

SUMMARY OF WORKSHOP SESSION C: SURFACE PROPERTIES, MEASUREMENTS AND TREATMENTS*

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Abstract

This is a summary of Session C of the ECLOUD'04 workshop. The session was dedicated to Surface Properties, Measurements and Treatments. Much progress has been achieved in particle accelerator laboratories in the understanding and finding possible treatments to reduce the secondary electron yield at the surface and cure the electron cloud effect.

INTRODUCTION

Studies of possible ways to reduce the electron cloud effect in particle accelerators should primarily focus on a surface approach.

Furthermore, the surface secondary electron yield (SEY or δ) and the secondary electron energy spectrum are the crucial ingredients for the simulation of the electron cloud effect. The success in predicting the electron cloud effect in particle accelerator depends on the actual knowledge of the surface status of the particular vacuum chamber under study. Recent secondary yield related measurements and possible surface treatments are presented.

LIST OF PRESENTATIONS

The contributions presented in the Surface Properties session:

- *Vacuum and electron cloud issues at the GSI present and future facilities*, G Rumolo, GSI
- *Surface related properties as an essential ingredient to e-cloud simulations*, R. Cimino, LNF-INFN
- *Instrumental Effects in Secondary Electron Yield and Energy Distribution Measurements*, R. Kirby SLAC
- *SEY and electron cloud build-up with NEG materials*, A. Rossi, CERN
- *Design and Implementation of SNS Accumulator Ring Vacuum System with Suppression of Electron Cloud Instability*, H. Hseuh, BNL
- *Experimental Results of a LHC Type Cryogenic Vacuum System Subjected to an Electron Cloud*, V. Baglin, CERN
- *Suppression of the effective SEY for a grooved metal surface*, G. Stupakov, SLAC

SUMMARY OF THE SESSION AND PRESENTATIONS

Vacuum and electron cloud issues at GSI

G. Rumolo gave an overview of the GSI existing machines and the future international accelerator projects,

vacuum requirements and beam life-time due to the dynamic vacuum, measurements of the ion desorption yield, simulations of the e-cloud in the SIS18 and SIS100/300 projects: thresholds for build up and instability. The vacuum is a serious concern and may limit the performance of the GSI future project machines.

The number of U28+ that we can inject into the SIS18 is limited by a vacuum instability driven by ion losses (Ion Stimulated Desorption). Presently the threshold is still well below the goal value required to inject 10^{12} U28+ into the SIS100. Studies of coating efficiency and/or collimators as possible solutions are still in progress. During the next shutdown, they will install chambers coated with TiZrV non-evaporable getter (NEG) in one super-period. The use of U73+ is also considered as a possible alternative, even if the intensity would be lower due to space charge. G. Rumolo also presented an extended set of simulations for the electron cloud build-up in the future machine upgrade and projects. Simulation results were obtained with the simulation code ECLOUD. In particular, a parametrization for elastically reflected electrons of unity for low electron energy has been used, as recently proposed and supported by recent measurements by R. Cimino and I. Collins, see below.

The actual SIS18 could suffer from electron cloud when upgraded to become an injector for the future SIS100 machine. Nevertheless, in the case of the upgraded SIS18, the secondary electron yield threshold for electron cloud formation is rather high with a peak SEY value or δ_{\max} ~ 2.1 , see Fig. 1. Thus, it is conceivable to assume that vacuum chambers with a SEY below this threshold value are easily provided.

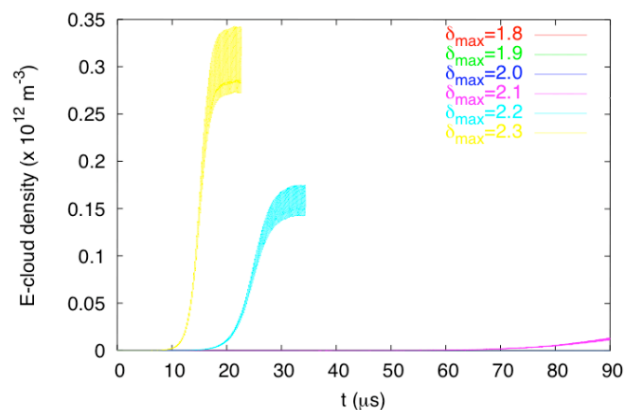


Figure 1. Electron cloud build up in a field-free region of the SIS18. Four bunches are present.

In the future machines SIS100/300, too, the threshold for e-cloud formation is high, especially for smaller beam

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pipe radii. Both in the case of SIS18 and SIS100/300 the SEY thresholds are lower in dipole regions. Single bunch head-tail instability estimations show that saturation values in the order of 10^{11} e/m³ are enough to cause beam instability.

The only concern is that, due to beam losses, there might be accumulation of electrons up to relatively high densities. G. Rumolo remarked that the recently proposed parametrization for elastically reflected electrons makes a significant difference in the predictions of the electron cloud build-up.

In conclusion, the electron cloud should not harm the performances of the future GSI projects.

Non-evaporable getter materials

Adriana Rossi reported on the latest developments in the research of non-evaporable getter vacuum chamber coatings for the LHC. TiZrV thin films (thickness 1 μ m) deposited onto chemical polished copper substrates, once activated show an important reduction in the SEY value. After 2 h at the so-called activation temperature ~ 180 C, TiZrV coatings start to act as vacuum pumps and show a reduction of δ_{\max} from an *as received* value of 2.0 to a value ~ 1.1 . CERN measurements of recontamination with gasses CO, CO₂ or H₂O vapors result in a small re-increase of the SEY $\Delta\delta \sim 0.1$. Thus, no electron cloud activity is expected for a vacuum chamber coated with NEG and subsequently activated. To verify the effectiveness of the coatings to reducing the electron cloud build-up, vacuum chambers coated with NEG material have been installed in the SPS accelerator at CERN, and tested with LHC-type beams during machine development studies, Fig 2. Electron detectors are installed in the chamber to measure the electron cloud current and activity.



Figure 2. Vacuum chambers with TiZrV non-evaporable getter thin films coatings have been installed in the SPS accelerator at CERN to test the effectiveness of the activated NEG materials on the electron cloud build up.

A. Rossi showed very promising experimental results for the NEG coating materials. The experimental results may be summarized as in Table 1.

Table 1. Electron-cloud build up measurements for the NEG coated chambers installed in the SPS. One cycle refer to exposition to air atmospheric pressure and re-activation.

NEG status	Expected δ_{\max}	Measured
Non-activated	> 2	e-cloud
Activated and saturated	~ 1.2	NO e-cloud
Cycled 7 times (air+act)	1.4	NO e-cloud

In particular, a NEG chamber activated and saturated, with an expected $\delta_{\max} \sim 1.2$, showed no electron cloud activity.

Elastically reflected low energy electrons

R. Cimino presented recent SEY measurements and discussed surface-related properties as an essential ingredient to e-cloud simulations. Measurements of the SEY and the secondary emitted electron energy spectrum were performed at CERN.

Remarkably, a secondary electron yield approaching unity has been measured for very low primary electron energy, as shown in Fig. 3, for an as received and a fully electron conditioned copper surface. The energy distribution of such emitted electrons is very important for electron cloud simulations.

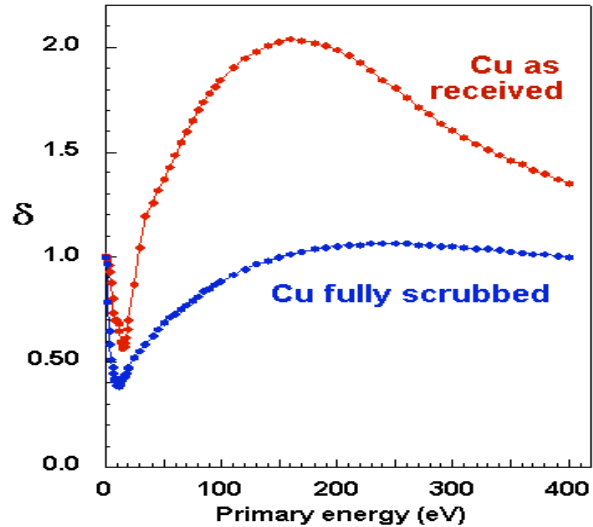


Figure 3. Secondary electron yield measurements for an as received and an electron conditioned or scrubbed sample. In particular, the SEY approaches unity for very low primary electron energy.

Low-energy electrons have a long survival time, in agreement with observation at PSR, LANL and at SPS. Reflected electrons are not absorbed at the wall and do not directly contribute to the heat load. However, they will be accelerated by the following bunches, gaining energy and generating more secondary electrons or

depositing higher power onto the vacuum chamber wall, which is of primary concern for the LHC beam screen.

In this respect, R. Cimino recommended that electron cloud simulations should be updated with a parametrization that take into account the possibility of a high reflectivity at very low incident electron energy.

Instrumental Effects in Secondary Electron Yield and Energy Distribution Measurements

R. Kirby discussed possible instrumental effects and artifacts that may affect the measurements and lead to misleading results, especially when operating with low or very low energy electrons.

After comparing the different systems for the laboratory measurements of the SEY, pointing out the strengths and weaknesses of three principal measurement methods, R. Kirby discussed the possible related undesired effects.

Possible collateral effects during the measurements of the SEY and the secondary energy spectrum are

- Secondary electrons may be generated internally into the electron gun source increasing the current of the effective “primary” electron beam
- Secondary and tertiary electrons may be generated from the vacuum chamber or inside a Retarding Field Analyzer (RFA) system
- The surface may be irreversibly modified by the incident electron beam used for the measurements (electron stimulated desorption, surface carburization or oxidation and damages)
- When measuring thin film coated materials, the substrate material may affect the effective SEY of the coating materials, see Fig. 4
- Near-zero primary electron energy measurements are very difficult and the interpretation of the results should take into account the possibility of stray field effects, gun filament/sample voltage difference or Bragg reflection peaks.

Suppression of the Electron Cloud in the SNS Accumulator Ring

A large simulation and experimental effort is underway to avoid the possible electron cloud instability in the SNS accumulator ring under construction at Oak Ridge, TN. The ring of the 1.4 MW neutron spallation source may suffer of trailing edge multipacting in a similar formation mechanism as in the PSR ring, LANL. In long proton bunches machines, like the PSR and SNS, the electron cloud formation and instability mechanism are different from that in short bunches machines. In the SNS, due to the high beam intensity $1.6 \cdot 10^{14}$ particles per bunch, the length and intensity profile of the bunch, a large electron multiplication may occur on the bunch tail if the secondary electron yield at the beam pipe wall is sufficiently large. This effect may explain why the tail becomes firstly unstable in the PSR.

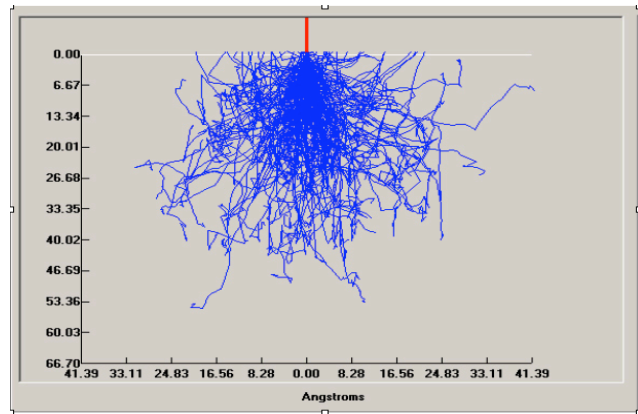


Figure 4. Simulated 500 eV electron penetration on a TiN surface material. The electron incident direction is orthogonal to the surface. The shower of secondaries is shown. Dimensions are in Angstroms.

H. Hseuh showed the work undergoing to reduce the SEY at the vacuum chamber surface. The SNS ring vacuum chambers are in the process to be coated with 100 nm TiN by DC magnetron sputtering at high sputtering rate with permanent magnets and low sputtering pressure.

An interesting and important correlation has been found between the SEY and the coating vacuum pressure. Higher coating pressures generally result in lower SEY values. TiN samples produced at BNL Brookhaven, have been sent to CERN and SLAC to be analyzed.

The peak SEY of TiN samples may be as low as 1.5-1.8, which may not be sufficient to avoid the electron cloud mechanism in the SNS ring. To reduce further the SEY, at SNS they are relying on the electron conditioning or beam scrubbing mechanism, which should decrease the yield to acceptable low values.

Note that gas recontamination may limit the efficiency of beam scrubbing and the reach of SEY values low enough, as described in the next paragraph.

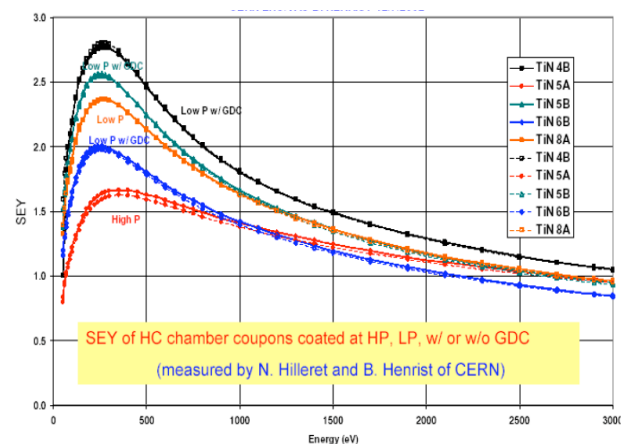


Figure 5. TiN samples produced at BNL, measured at CERN. A correlation between coating pressure and SEY is shown.

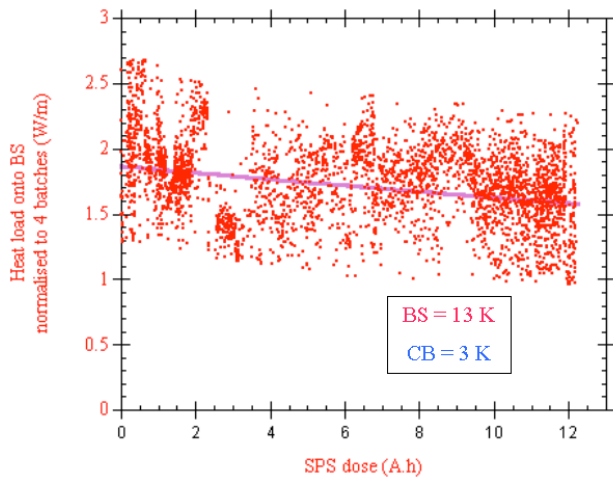


Figure 6. Heat load as a function of the electron dose measured in the beam screen of the COLDEX vacuum chamber installed in a dedicated SPS field-free region.

In the field-free regions the use of solenoid windings should be sufficient to reduce the electron multiplication and confine the electron in the proximity of the chamber wall. Beam position monitors may also be efficient as clearing electrodes when biased at few hundreds Volts. Coating of the ceramic chambers and extraction kickers is also underway.

LHC-type Cryogenic Vacuum System Subjected to an Electron Cloud

V. Baglin reported on the recent measurements in the COLDEX experiment installed in the SPS accelerator and discussed the implications for the electron cloud in the LHC cryogenic environment.

The COLDEX set-up is installed in a field-free region with a closed geometry, 2.2 m long. In particular, in the system it is possible to measure the heat load at the surface. An heat load onto the beam screen is measured to decrease with electron dose: beam conditioning. A heat load 1.6 W/m observed during the 2003 scrubbing run is compatible with a $\delta_{\max} \sim 1.2-1.3$, with an estimated electron dose at the surface of 20 mC/mm². V. Baglin compared experiment results with simulation expectations showing that the agreement between simulations and experiments is reasonable.

V. Baglin pointed out that electron conditioning or beam scrubbing takes place only when an electron cloud is present. Note here that when measuring the electron conditioning effect in laboratory based systems, a constant electron beam dose is applied to a sample and the reach of very low SEY is possible.

In a particle accelerator environment the electron conditioning effect takes place only when an electron cloud is present. Once reached a threshold SEY the electron cloud is largely diminished. Then, gas recontamination at the surface may re-increase the SEY limiting the efficiency of beam scrubbing and the reach of SEY values low enough.

This has implication for electron conditioning in the LHC and in particle accelerators in general, where dedicated period are required to perform the conditioning, conditioning shall be performed at injection, and most importantly the effect of conditioning might be lost and “over-conditioning” at higher beam intensity might be necessary. Based on an exponential fit of the measured heat load, assuming ~ 1.5 W/m could be dissipated onto the beam screen, V. Baglin suggested that a dose of 200 A-h would be required to reduce the dissipated heat load to ~ 1 W/m, at nominal LHC current.

Operations at 75 ns bunch spacing confirm that the heat load is reduced with respect to the 25 ns nominal bunch spacing, in agreement with previous simulation results.

In conclusion, in the SPS, a significant heat load, a conditioning effect, and a vacuum surface cleaning are observed at cryogenic temperature. COLDEX observations are in a rather good agreement with the ECLLOUD code. Other means to reduce the electron cloud shall be studied and validated in existing machines. More laboratory and machine data related to beam conditioning and condensed gases are required to benchmark the codes and predict more accurately the LHC behavior. The operation with the LHC requires a deep understanding of the electron cloud phenomena to control the radiation level, the emittance blow up and the vacuum life times.

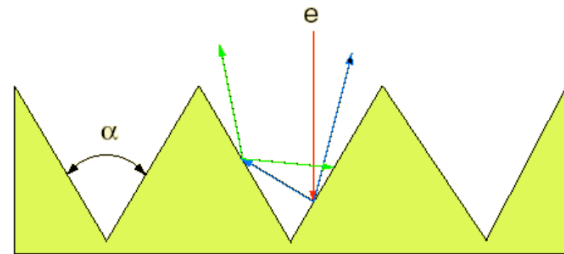


Figure 7. Triangular grooved metal design profile. The secondary electrons are trapped in the artificially increased roughness surface and the SEY is considerably reduced.

Suppression of the effective SEY from a grooved metal surface profile

G. Stupakov described a new approach, originally proposed at CERN, to reduce the secondary electron yield by means of a specially designed triangular metal surface profile. Typically, secondary electrons are less likely to leave the surface if the surface roughness is high. The surface roughness may be artificially increased by specially designed groove surface. G. Stupakov showed recent simulations performed at SLAC of the effective SEY including a triangular shape surface profile. The effective SEY is a function of the angular aperture of the triangular groove. Assuming an angular aperture $\alpha = 40^\circ$ of the triangular groove profile, see Fig 5, the simulated SEY decreased by a factor ~ 2 in a field-free region.

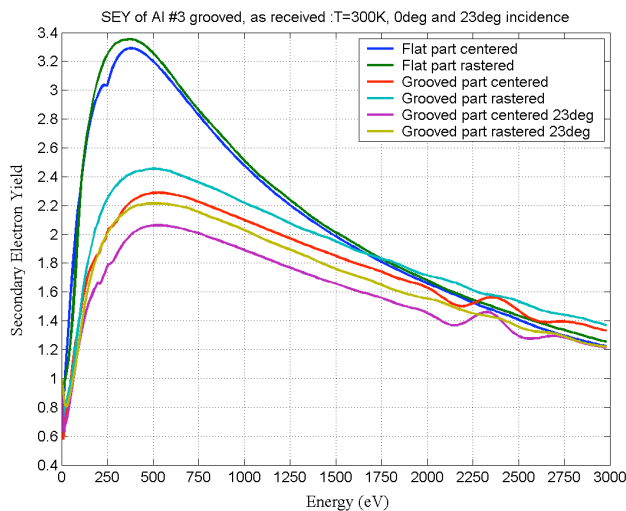


Figure 8. Reduction of the secondary electron yield to for a triangular grooved aluminum sample measured at SLAC. Triangular groove angular aperture is $\alpha=40^\circ$. During the measurements, the electron beam is operated either in centered or in raster mode.

Triangular grooved surface samples have been manufactured and the SEY measured at SLAC. Experimental results show that for aluminum 6063 samples an effective reduction of 35% is achieved, see Fig. 6. G. Stupakov also mentioned that when including a dipole magnetic field in the simulations the SEY reduction is less effective for a triangular groove.

Very promising is the alternative rectangular groove profile suggested at SLAC. In particular the depth and step between the grooves may be designed to achieve SEY lower than 1. Very recent measurements show that a remarkable SEY reduction as low as $\delta_{\max} \sim 0.7$ can be achieved with a rectangular design profile. Simulations for a rectangular design profile in magnetic field regions are needed.

Following these simulation and experimental results, a plan to install dedicated grooved vacuum chambers in the PEP-II accelerator is foreseen for the year 2005.

COMMENTS

Outstanding progresses in the study of the surface properties have been lately achieved in the effort to reduce the electron cloud instability in particle accelerators.

In particular

- The effective SEY can be greatly reduced by means of rectangular and triangular grooved surface profile - simulations and experimental result at SLAC and originally CERN.

- SEY measurements at CERN show that a secondary electron yield approaching unity is measured for very low primary electron energy, suggesting a high component of the elastically reflected electron.
- Electron conditioning or beam scrubbing and a vacuum surface cleaning are observed also at cryogenic temperature (COLDEX experiment in the SPS accelerator at CERN).
- TiZrV NEG has been successfully tested to reduce the electron cloud formation with dedicated chambers in the SPS accelerator at CERN
- A correlation between TiN coating pressures and SEY is found, suggesting that highest TiN coating pressures should result in lower SEY values.

Furthermore, simulations show that in the future GSI machine projects the electron cloud should not be an issue. In the measuring of the SEY, one should pay special attention to possible instrumental effects and artifacts which may affect the measurement results and a complete understanding of the secondary emission process, especially when dealing with low and very low energy electrons.

Concerning to the electron conditioning or beam scrubbing effect, one should distinguish between the effect measured in laboratory systems and in the accelerator environment. In laboratory system measurements during electron conditioning, a constant electron beam dose is applied to a sample and the reach of very low SEY $\delta_{\max} \sim 1$ is possible.

In an accelerator vacuum chamber the electron conditioning effect takes place only when an electron cloud is present and one should take into account the competing effect from surface gas recontamination, which may limit the efficiency of beam scrubbing and hence the attainment of low enough SEY values. This may explain why an electron cloud activity is present in particle accelerators even after years of operations.

A possible simple way to counteract this effect is the “over-conditioning” at higher beam intensity, which might be necessary, for example, in the case of the LHC.

ACKNOWLEDGEMENTS

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